

BELLCOMM, INC.

1100 Seventeenth Street, N.W. Washington, D. C. 20036

SUBJECT: Suggested Test Program to Establish Effectiveness and Toxicity of CBrF₃ (Bromotrifluoromethane) as a Spacecraft Fire Extinguishing Agent - Case 320

DATE: April 10, 1968

FROM: J. D. Richey

ABSTRACT

Data presently available does not permit valid evaluation of the advantages and disadvantages of CBrF₃ as a spacecraft fire extinguishing agent. A test program is suggested that will determine the effectiveness of CBrF₃ against fires and establish the hazards to humans of the undecomposed CBrF₃, and of the combination of undecomposed CBrF₃, pyrolysis and combustion products of the spacecraft combustibles, and pyrolysis products of CBrF₃. The test results should provide the basic information needed for development of CBrF₃ fire extinguishing systems and operating procedures for spacecraft.

(NASA-CR-95530) SUGGESTED TEST PROGRAM TO ESTABLISH EFFECTIVENESS AND TOXICITY OF CBRF3 /BROMOTRIFLUOROMETHANE/ AS A SPACECRAFT FIRE EXTINGUISHING AGENT (Bellcomm, Inc.) 8 p

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MEMORANDUM FOR FILE

Introduction

Should fire break out in a manned spacecraft, in spite of the precautions that have been taken, a means of rapid extinguishment is needed to minimize damage to equipment and injury to personnel. There are three general classes of fire extinguishing agents suitable for use in air and pure oxygen atmospheres: 1) those that cool the fire, 2) those that prevent oxygen from reaching the fire, and 3) those that inhibit the chemical reaction in the combustion process. Water extinguishes fires by cooling; CO_2 ; N_2 , powders, and foams extinguish fires primarily by excluding oxygen; and the halogenated gases including Bromotrifluoromethane (CBrF_3 - Freon 1301) operate by breaking the chain reaction in the combustion process. For particular applications, advantages and disadvantages may be cited for specific agents or classes of agents.

Tests have shown that, for certain applications, CBrF_3 is a highly effective fire extinguisher especially if applied at an early stage of a fire. Furthermore, CBrF_3 is a gas that can readily permeate a spacecraft without damaging equipment. However, in enclosed spaces, undecomposed CBrF_3 and the pyrolysis (decomposition) products of CBrF_3 present potential toxic hazards to humans. Condensate containing pyrolysis products of CBrF_3 could present a corrosion hazard.

Historically, a man's progress includes many instances where a recognized small danger is accepted in order to eliminate a larger danger. For example, antibiotics are very effective against many dangerous and often fatal diseases, but occasionally undesirable and even fatal reactions occur. Similarly, cyclopropane is a very useful anesthetic even though its use at times has fatal consequences. These agents are in general use today because their advantages outweigh their disadvantages. This risk tradeoff approach might well be applied to the issue of CBrF_3 usage in the space program. Unfortunately, the risk tradeoff cannot be made because necessary quantitative data on three important properties of CBrF_3 ; namely, speed of fire extinguishment, and the added dangers of the undecomposed CBrF_3 and the

pyrolysis products of CBrF_3 are seemingly contradictory, incomplete, or difficult to extrapolate to manned spacecraft applications. Examples that illustrate this situation are:

1. Tests have demonstrated that 7% by volume of CBrF_3 is capable of extinguishing liquid hydrocarbon fuel fires in a normal atmosphere in a fraction of a second, and that on a weight and volume basis, it is more effective than any other chemical against Class B (flammable liquid) and Class C (electrical fires).^{1, 2} In a test conducted in a boilerplate Apollo Command Module, a stream of CBrF_3 directed against a block of polyurethane foam burning in an atmosphere containing 80% O_2 by volume, did not fully extinguish the fire.³ The total amount of CBrF_3 released was approximately 4% of the volume of the boilerplate. The concentration of CBrF_3 in the stream of gas that flowed around the burning foam block is not known, but is believed to be greater than 4%. The concentration of CBrF_3 that would be effective for this hyperoxic atmosphere is estimated from other tests to be 50%.^{4, 5}
2. The functioning of the hearts and central nervous systems of rats, mice, dogs and monkeys is affected by their breathing air or oxygen combined with CBrF_3 .^{6, 7, 8} In tests, these subjects breathed air or oxygen with volumetric concentrations of CBrF_3 that varied from a few per cent to 80%. Severe epileptiform seizures appeared spontaneously in dogs breathing atmospheres containing 50% or greater of CBrF_3 . Fibrillation could be induced in dogs, breathing atmospheres of 80% CBrF_3 , by injections of 10 mg of epinephrine (an adrenal hormone) per kg of body weight. The mass of injected epinephrine was much larger than the delivery capability of the adrenal glands. In contrast to the dogs, monkeys became soporific instead of convulsive, and fibrillation could not be induced in the monkeys. After they were returned to a normal atmosphere, the hearts and central nervous systems of the dogs and monkeys began to function normally. Apparently, CBrF_3 is not dissolved in body tissue and, thus, does not have cumulative effects. Brief tests on three human subjects breathing mixtures of 1, 3, 5, 7 and 10% CBrF_3 and air for 3 - 3 1/2 minutes resulted in normal electrocardiograms during each exposure. The subjects reported a light-headedness similar to that produced in the first stage of general anesthesia by

ether or nitrous oxide when they breathed the 7 and 10% concentrations of CBrF_3 . The experiment indicated that exposure to a concentration greater than 7% CBrF_3 for longer than four or five minutes may result in impaired function or unconsciousness.⁷ It is not known if human reaction to the CBrF_3 and epinephrine will be similar to the response of either dogs or monkeys.

3. The Underwriters' Laboratories have given CBrF_3 a toxicity rating of 6. Both CO_2 and carbon tetrachloride are more toxic which is shown by their ratings of 5a and 3. The U. S. Army Chemical Center ranks the agents in the same general order.¹
4. CBrF_3 has been heated to temperatures above 800°C in a reducing flame. The resulting pyrolysis products were predominantly HF (Hydrogen Fluoride), a very active chemical. Laboratory animals that breathed atmosphere containing CBrF_3 developed edema of the lungs. The severity ranged from slight to fatal dependent upon the concentration of the pyrolysis products and the exposure time.⁹

Suggested Test Program

A realistic appraisal of the relative merits of CBrF_3 fire extinguishing systems for spacecraft applications should include evaluation of: (1) the direct hazards of injury or damage to personnel and equipment by heat and flame, (2) the mission hazards resulting from failure of critical equipment brought about by fire or by use of the extinguishing agent, (3) the toxic hazards of the combustion and pyrolysis products of spacecraft materials (previous tests of wood and hydrocarbons as fuels are not applicable to spacecraft), and (4) the combined toxic hazards of the undecomposed extinguishing agent and its pyrolysis products, and the combustion and pyrolysis products of the spacecraft combustibles. The last two hazards should be evaluated initially under the flight and test cell atmosphere and gravity conditions to be encountered on present Apollo systems and future AAP systems. These are: air at 14.7 psia and 1 g, 60% oxygen - 40% nitrogen at 16.0 psia and 1 g and 10 g, pure oxygen at 5 psia and 0, 1/6, 1, and 10 g, and a 69% O_2 and 31% N_2 atmosphere at 5 psia and 0 and 1 g. Practical considerations will restrict early tests to a 1 g environment. Later, if feasible, tests should be conducted in 0 and 10 g environments.

As far as is known, there are no test programs to develop the data. The detailed design of a test program to achieve these objectives should be undertaken by experts in

this field. The test program should result in a range of evaluated physiological data that could be used directly by engineering personnel to design and develop CBrF₃ fire extinguishing systems for use in spacecraft. Two suggested groups of tests will illustrate the type of program envisioned.

1. A group of toxicity tests similar to those conducted at Wright Patterson Air Force Base should be performed where the test subjects breathe CBrF₃ in combination with air at 14 psia and 1 g and a 60% oxygen - 40% nitrogen atmosphere at 14.7 psia and 1 g. Appropriate test subjects should be used. The tests should be extended to include oxygen at 5 psia, and a 2 gas combination (for example, 69% O₂ and 31% N₂ for AAP) at 5 psia and 1 g. The effects of various concentrations of CBrF₃ on the test subjects should be measured and evaluated.
2. A second group of tests to determine the additional toxic load resulting from the pyrolysis products of CBrF₃ should be conducted using spacecraft combustibles as fuels and appropriate test subjects. Preliminary tests should be performed with each combustible to determine the minimum concentration and rate of application of CBrF₃ needed for rapid extinguishment. Then, several sets of two tests each should be performed for each combustible using carefully measured, identical quantities of the combustible materials and the previously determined minimum concentration and rate of application of CBrF₃. In the sets of tests, the fire should be allowed to burn for various selected and measured intervals prior to the application of CBrF₃. The time from ignition to extinction and the time from ignition to the time at which the temperature of the combustibles drops below that necessary to pyrolyze the CBrF₃ or the combustible, whichever is the lowest, should be measured. Also, the rate of application of CBrF₃, the volumetric concentration of CBrF₃ applied, the mass of fuel burned, and the fire temperature and the volumetric composition of the test chamber atmosphere just prior to the extinguishment of the fire, should be measured. In the second test of each set, the combustible should burn in the chamber until the mass of material burned is the same as in the first test. At that time, the burning combustible should be removed from the chamber. The fire temperature and the volumetric composition of the test chamber atmosphere at the time the burning combustible is removed from the test chamber should be measured. In each test, animal subjects should be

exposed to the test chamber atmosphere for varying periods of time but not to the heat of the fire. The animals should be sacrificed and examined to determine the biological effects of the gaseous combustion and pyrolysis products.

Test Results Expected

It is expected that after the fires, the test chamber atmospheres will consist of the gases present prior to the fire, gaseous combustion products, and gaseous pyrolysis products, if any, of the combustible, most of the original volume of undecomposed CBrF_3 , and a small volume of the pyrolysis products of CBrF_3 . The pyrolysis products of the CBrF_3 will be a minimum if the proper concentration of CBrF_3 is rapidly applied. The tests should establish the effectiveness of CBrF_3 as a fire extinguisher for spacecraft applications, the physiological danger of undecomposed CBrF_3 , the physiological danger resulting from the combustion and pyrolysis products of the fuels, the physiological dangers resulting from the combination of undecomposed CBrF_3 , the pyrolysis products of CBrF_3 , and the combustion and pyrolysis products of the combustibles. Then, tradeoffs that include consideration of the direct hazards of injury or damage to personnel and equipment by heat and flame, and the mission hazards brought about by fire or use of the extinguishing agents can establish the value of a CBrF_3 fire extinguishing system. The test data should provide the basic information needed in the development of CBrF_3 fire extinguishing systems and operating procedures.

A program consisting of tests such as those suggested should be implemented promptly so that if the test and tradeoff results demonstrate that CBrF_3 offers advantages as a spacecraft fire extinguishing agent it can be put into use at an early date to increase crew safety in the manned space program. The first step in implementing the test program would be to develop a detailed test plan including specifications for required equipment. The plan could serve as a basis for cost and schedule estimates.

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Attachment
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BELLCOMM, INC.

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